NASA TECHNICAL MEMORANDUM

NASA TM-73855

(NASA-TM-73855) EFFECTIVENESS OF AN INLET FLOW TURBULENCE CONTROL DEVICE TO SIMULATE FLIGHT NOISE FAN IN AN ANECHOIC CHAMBER (NASA) 16 p HC A02/MF A01 CSCL 20A

N78-13856

Unclas
G3/71 55246

NASA TM-73855

EFFECTIVENESS OF AN INLET FLOW TURBULENCE CONTROL DEVICE TO SIMULATE FLIGHT FAN NOISE IN AN ANECHOIC CHAMBER

by R. P. Woodward, J. A. Wazyniak, L. M. Shaw,
and M. J. MacKinnon
Lewis Research Center
Cleveland, Ohio 44135

TECHNICAL PAPER to be presented at the
Ninety-fourth Meeting of the
Acoustical Society of America
Miami, Florida, December 13-16, 1977

EFFECTIVENESS OF AN INLET FLOW TURBULENCE CONTROL DEVICE TO SIMULATE FLIGHT FAN NOISE IN AN ANECHOIC CHAMBER

R. P. Woodward, J. A. Wazyniak*, L. M. Shaw,

and M. J. MacKinnon

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

E-9444

ABSTRACT

A hemispherical inlet flow control device was tested on a 50.8 cm. (20-inch) diameter fan stage in the NASA-Lewis Anechoic Chamber. The control device used honeycomb and wire mesh to reduce turbulence intensities entering the fan. Far field acoustic power level results showed about a 5 dB reduction in blade passing tone and about 10 dB reduction in multiple pure tone sound power at 90% design fan speed with the inlet device in place. Hot film cross probes were inserted in the inlet to obtain data for two components of the turbulence at 65 and 90% design fan speed. Without the flow control device the axial intensities were below 1.0%, while the circumferential intensities were almost twice this value. The inflow control device significantly reduced the circumferential turbulence intensities and also reduced the axial length scale.

INTRODUCTION

Turbofan engine noise investigations have shown considerable differences in fan noise levels between static and flight operation (ref. 1). In particular, the blade passing tone level is often much higher under static testing conditions. A plausible explanation of this phenomenon is offered by Hanson (refs. 2 and 3) in which atmospheric turbulence eddies are envisioned as being elongated as they are drawn into the statically-operating fan, thereby generating a tone at blade passing frequency as several blades pass through this disturbance. No significant tone noise generation from this source would be expected during flight since these eddies would enter the fan inlet with little distortion (i.e., elongation). Thus it is quite possible for part of the flight fan acoustic signature to be masked in traditional static testing.

Flight-observed reductions in the fan blade passing tone have been achieved in a wind tunnel (refs. 4 and 5). Reference 5 describes the acoustic testing of a model research fan in the NASA-Lewis 9   15 wind

*Presently employed by Pratt & Whitney Aircraft, West Palm Beach, Florida tunnel. At a tunnel flow of 41 m/sec (135 ft/sec) the fan blade passing tone was essentially reduced to the broadband level. These tests were expanded (ref. 6) to include hot film turbulence measurements in the fan inlet. The circumferential turbulence intensity, measured in the fan inlet with a 41 m/sec tunnel flow, was reduced to 20% of the value measured without tunnel flow.

Inflow disturbance control appears to be the key factor in achieving flight-type fan noise during static testing. Several investigators have attempted to control inlet airflow with screens and flow straightening grids (refs. 7-11). Inlet screens alone have been shown to produce modest reductions in both turbulence intensities and blade passing tone levels (refs. 7-9). Good results were obtained with a ribless hemispherical honeycomb device, the design of which is described in reference 10 and the test results presented in reference 11. In these tests, conducted in an anechoic chamber, the fan blade passing tone was reduced by about 10 dB. Inlet duct hot film turbulence measurements also showed reduced intensities with the honeycomb device in place.

A honeycomb-screen inlet flow control device was tested on a research fan in the NASA-Lewis 9x15 anechoic wind tunnel with no tunnel flow (ref. 6). The fan blade passing tone level was somewhat reduced by the inlet control device, but not to the degree observed for the flight simulation tests with tunnel flow on the same fan. Inlet duct hot film turbulence measurements taken during these tests showed reduced circumferential intensities with the inlet flow device in place.

In the present study, the honeycomb-screen inflow control device reported in reference 6 was used on a research fan stage in an anechoic chamber to reduce the inflow turbulence and thus approach flight-type fan noise. Cross-film turbulence measurements were made in the fan inlet and related to acoustic results. The research fan was tested in three configurations which varied stator number and rotor-stator spacing. The design configuration had sufficient stator vanes to be cut-off with respect to propagation of the fundamental tone due to rotor-stator interaction. The rotor-stator spacing for this configuration was 3.5 mean rotor chord lengths. The same rotor was also tested with a reduced number of stator vanes, resulting in a non-cut-off fan stage, at rotor-stator spacings of 1.5 and 3.5 rotor chord lengths.

FACILITY DESCRIPTION

Anechoic Chamber

The results presented herein were obtained in the NASA-Lewis Anechoic Chamber, which is described in detail in reference 9. Figure 1 is a photograph of the research fan installed in the anechoic chamber without the inlet flow control device. Plan and elevation views of the facility are given in figures 2(a) and (b). Calibration of the chamber showed it to have anechoic properties within 1 dB for frequencies above 500 Hz. The chamber may be operated in either a "muffler open" mode in which airflow primarily enters through the silencer, or in an aspirating mode in which the silencer is closed and air enters the chamber through aspirating areas on the chamber floor and walls. All of the results presented herein are for the aspirating mode of chamber operation.

Acoustic data. - Far field acoustic data were acquired at a 7.6 m (25 ft) radius at 0 to 90 degrees from the fan inlet axis (in 10 degree increments). Signals from the 0.64 cm (0.25 in.) microphones were reduced on line on a one-third-octave analyzer and also recorded on magnetic tape for further analysis. The boom microphone, seen in figure 1, was not used because of interference with the inlet flow control device support structure.

Research Fan

The research fan used in this study was designed with low-noise considerations such as large (3.5 mean rotor chord) rotor-stator spacing and blade-vane ratio selected to satisfy the fundamental rotor-stator interaction tone cut-off criterion of Tyler and Sofrin (ref. 12). A detailed report of the aerodynamic performance of this fan, obtained in a highly-instrumented facility, is given in reference 13.

The research fan was also tested in a non-cut-off mode in which the number of stator vanes was reduced from 112 to 88. This 88-vane stator fan stage was tested with rotor-stator spacings of 1.5 and 3.5 mean rotor chord lengths. These spacing modifications were accomplished using hardware from the tests reported in reference 13. For this modified stage only the circumferential spacing of the stator vanes was adjusted to allow the reduced number of vanes to be equally spaced. The vane setting angles were not adjusted. A computer study of this modification indicated that there should be little adverse effect on the fan performance. This non-cut-off configuration of the research fan was expected to have a fundamental tone more controlled by rotor-stator interaction, and therefore be less sensitive to inflow disturbances or their modification by the inflow control device.

A cross-sectional view of the research fan, as installed in the anechoic chamber, is given in figure 3. Also shown on figure 3 are some design parameters for the fan. A contoured flight-type inlet was used for these tests. An acoustically-treated annular flow splitter with axial support vanes was installed downstream of the fan to guide and stabilize the flow as it expanded radially into the exhaust collector, and to attenuate any aft fan noise which might be reflected back toward the fan from the collector.

Aerodynamic Instrumentation. - The research fan had sufficient aerodynamic instrumentation to establish the operating point in terms of pressure ratio and mass flow. This instrumentation included inlet thermocouples and static pressure sensors for inlet mass flow calculations, and total temperature and pressure rise measurements across the stage. These measurements were processed through a pressure multiplexing network and computer system to calculate aerodynamic parameters. The fan operating line was controlled by downstream valves at the collector exit. Performance parameters were corrected to standard day conditions of a temperature of 288.15 K (518.67° R) and an atmospheric pressure of 101325 Pa. (760 mm Hg.).

In-duct sound pressure. - An inlet duct sound pressure sensor was installed in the flight inlet as shown in figure 3. Signals from this sensor were processed in the same manner as those from the far field microphones. This in-duct sensor was not functional for all of the tests.

Turbulence measurements. - Axial and circumferential turbulence velocity components were measured in the fan inlet with a constant temperature cross film anemometer. Each film was 70 μm (0.0028 in.) in diameter and 1.25 mm (0.05 in.) long. The signals from the cross film were linearized, summed and differenced to obtain axial and circumferential velocity components and dc suppressed to preserve low frequency information before being recorded on magnetic tape. Analysis of the turbulence data was done off-line utilizing a digital signal processor. Intensities and scales were determined by the same methods as reported in reference 6. Data were recorded for probe immersions from 0.66 cm (0.26 in.) to 12.95 cm (5.1 in.) from the inlet duct outer wall. All inlet turbulence measurements were made with the design fan stage operating on the standard line.

Inlet Flow Control Device

The inlet flow control device was used in an effort to reduce the inflow disturbances entering the fan inlet, and thereby approach flight-type fan noise characteristics. Figure 4 is a photograph of the device installed on the fan in the anechoic chamber, and figure 5 gives construction details of the device.

The device was built in layered construction, with an inner layer of coarse screen as a base (70% open area) for the outer layers of finer screen (40% open area) and honeycomb. The honeycomb had an irregular shaped cell structure (see fig. 5) with an effective diameter of about 0.64 cm (0.25 in.) giving a length to diameter ratio of the honeycomb passages of about 8. In concept, the honeycomb would reduce the transverse components of the incoming flow disturbances, while the downstream screen would further reduce any residual turbulence. A necessary compromise in the construction was the use of a framework to support the turbulence-control screen. The effect of this structure was minimized by using thin ribs oriented to provide minimal blockage to the airflow. Flow tests were performed with this device on the research fan which showed the pressure drop through the device at 90% fan speed to be about 20 pa (0.003 psi), therefore having negligible effect on the fan operating point. Insertion loss measurements, performed with a speaker and a jet noise source with no airflow through the inlet flow control device showed the sound radiated through the device to be attenuated less than 1 dB from 0 to 90 degrees from the fan axis at least to a frequency of 20 k Hz.

DISCUSSION OF RESULTS

Fan Performance

The fan operating map (fig. 6) shows the aerodynamic performance of the research fan as designed with 112 stators spaced at 3.5 mean rotor chords and the modified configuration with 88 stators spaced at 1.5 chords. (The aerodynamic results for both configurations with 88 stators were essentially the same.) The aerodynamic results for the design fan (from ref. 13) are superimposed on this fan map. At higher fan speeds the 88 vane stator configuration shows reduced performance compared to that of the design fan. It was not possible to take data much further toward the "rear stall" line from reference 13 without audible indications of approaching stall. This condition seems to have been aggravated by the 88-vane stator modification. These data points closest to the stall line correspond to what is regarded as the standard operating line.

The 90% design fan speed was selected for most of the acoustic data reported herein. At this fan speed the blade tip speed is subsonic, but the relative blade velocities are supersonic -- high enough for shaft order tone generation. Also, there was good agreement between corresponding operating points with and without the flow control device at this fan speed.

Acoustic Performance

Sound pressure level directivity. - Directivity plots for the blade passing fundamental and first overtone (2 x BPF) were made from constant bandwidth (50 Hz) sound pressure level spectra. These spectra were averaged over 25.6 seconds. The directivity results presented in figure 7 are for 90% design fan speed and the choke operating line to allow inclusion of the cut-on (88-vane stator) results. Figure 7(a)

ORIGINAL PAGE IS
OF POOR QUALITY

shows both versions of the fan to have similar blade passing tone directivity without the inlet flow control device, indicating that without inlet flow conditioning, the fundamental tone is controlled by rotor-disturbance interaction for both fan configurations. The slightly higher results for the design stage might correspond to the higher mass flow and pressure ratio observed for this configuration (see fig. 6). The inlet flow control device reduces the fundamental tone level and exposes evidence of a lobed pattern in the passing tone directivity with both fan configurations, with peak values occurring at 40 and 60 degrees from the inlet at 90% design fan speed. Since the angular locations of these lobe-like protuberances do not change with blade-vane ratio, it seems probable that these structures relate to residual disturbances entering the fan with the inflow control device in place.

The first overtone directivity (fig. 7(b)) also shows a maximum value at 40 degrees with the inlet flow control. However, the lobe-like pattern is less pronounced than for the fundamental tone. The wind tunnel tests reported in references 5 and 6 noted a lobed directivity pattern for the first overtone, but not for the fundamental tone.

Sound pressure level spectra. - Constant bandwidth sound pressure level spectra are presented in figures 8 and 9. The far field results are for 90% design fan speed and 70 degrees from the fan inlet axis -- a location at which the inlet flow conditioning was effective in reducing the blade fundamental and overtone levels (see fig. 7). In addition, the generation of shaft-order tone levels were greatest toward the back angular locations, and were well-established for the open inlet tests at 90% speed and 70 degrees from the inlet axis.

Figure 8 presents sound pressure level spectra for the design (112-vane stator) fan configuration operating on the standard line showing the effect of inlet flow conditioning in the far field and in the inlet duct. In the far field (fig. 8(a)) the inlet flow control device is seem to reduce the blade passing tone level by 10 dB and the first overtone by 5 dB. In addition, the shaft order tones were reduced to nearly broadband levels.

The inlet duct sound pressure level spectra (from the sensor closest to the inlet highlight), figure 8(b), shows essentially the same reductions, although the blade passing tone reduction is increased to 16 dB. The tone contribution at about 16 K Hz seen in the inlet duct spectra (Fig. 8(b)) is not evident in the far field data (fig. 8(a)) with the flow control device. It is possible that this tone may be locally generated by airflow at the sensor. The modified (88-vane) fan results are not included in this comparison because the fan appeared to be operating near a stall condition.

The acoustic effect of the inlet device for the fan operating on the choke line is shown in figure 9. Data for the 112 and the 88 vane configurations (with 1.5 chord rotor-stator spacing) are shown for the 70 degree microphone and 90% design fan speed. The blade passage tone reduction with the inlet device for the design (112-vane) fan is about 10 dB (fig. 9(a)) and the shaft order tones were reduced to near broadband levels with the inlet device. The same results were observed for the fan at the standard operating line (fig. 8(a)).

The 88-vane stator fan stage is not cut-off and with the 1.5 chord spacing might be expected to generate considerable rotor-stator interaction noise at the blade passing frequency. However, as shown in figure 9(b), the blade passing tone reduction with inflow control is almost as great as for the design, cut-off fan stage. This result suggests that for the inflow disturbances present, the rotor-inflow interaction noise at 90% design speed is much more significant than the rotor-stator interaction noise even with a 1.5 mean chord rotor-stator spacing.

There appears to be some difference in the effect of the inlet flow control device on the broadband levels in the far field and inlet duct suggesting possible noise reduction through the device with airflow. In the inlet duct (fig. 8(b)) the broadband levels with inlet flow conditioning essentially follow the minimum values observed for the open inlet broadband. However, in the far field (figs. 8(a) and (9)) the broadband levels with flow conditioning appear to be about 3 dB below the minimum values for the open inlet. This broadband difference does not appear to be frequency-related, and was observed at other far field angular locations. The acoustic calibration tests of the inlet flow control device with no airflow indicated sound reductions to be less then 1 dB. Thus there may be additional broadband sound reduction through the device associated with airflow and actual fan model characteristics. Additional flow tests with a known noise source which better simulates a fan would be useful in the cage calibration procedure.

Time history. - The blade passing tone time history gives an indication of the steadiness of the tone which is an indication of the effectiveness of the inlet device in removing random inflow disturbances. In actual flight (ref. 8) and tunnel-simulated flight (refs. 5 and 6) the blade passing tone level fluctuation with time were greatly reduced from static values. The hemispherical honeycomb inlet cage of reference 11 was effective in reducing the blade passing tone fluctuation of a rotor-alone fan.

Blade passing tone time histories for the design research fan are presented in figure 10 for the far field at 70 degrees from the fan inlet axis. The inlet flow control device is seen to somewhat reduce the tone level fluctuations, but the reduction was not as convincing as that observed for the flight simulation tests of references 5 and 6 Similar results were seen in the inlet duct.

In the tunnel flight simulation tests of reference 6 a turbulence probe was inserted into the inlet airflow. The probe maximum diameter was 0.64 cm (0.25 in.) and the probe was installed about 40 diameters from the rotor face. The blade passing tone level during flight simulation proved to be very sensitive to the presence of the inlet probe, with the tone level being increased to static levels with the probe inserted 10 cm into the inlet flow. Consequently, it is reasonable to expect the results with the inlet flow control device to be quite sensitive to any disturbances that might be generated by the device structure. There is concern over possible flow irregularities being generated at the rib-honeycomb junctions of the inlet control device used in this study. Thus a further refinement in the inlet flow control device would be to eliminate these support struts, as was done for the control device described in reference 10.

Sound power level. - Sound power level calculations were made from one-third-octave sound pressure level results over the forward arc (0 to 90 degrees from the fan inlet axis).

Figure 11 presents sound power level spectra for the design (112-vane) fan configuration operating on the choke line, showing the effect of the inlet flow control device. The 90% design fan speed results (fig. 11(a)) correspond to the constant bandwidth sound pressure level spectra of figure 8(a). The previously discussed reductions in the blade passing tone, first overtone, shaft order tones, and broadband noise with the inlet flow device are seen in this figure.

At design fan speed (fig. 11(b)) the presence of inlet flow control device was not very effective in reducing the shaft order tones at frequencies approaching the fundamental. Lower frequency shaft order tones were still reduced by inlet flow conditioning. At this speed the blade tip relative Mach number is 1.135 (ref. 13).

An indication of the effectiveness of the inlet flow control device for the three stator configurations over the test fan speed range is given in figure 12. The effect on the blade passing tone of stator vane number is given in figure 12(a) and of rotor-stator spacing for the cut-on (88-vane) stage in figure 12(b). Corresponding results for the first overtone are given in figures 12(c) and 12(d). Disadvantages of using one-third-octave analysis include occasional sharing of the tone content between two adjacent filters, and inclusion of unwanted additional spectral energy in the fundamental and overtone sound power level calculations -- a problem particularly present with shaft order tones.

Essentially no difference is seen between the results for the fundamental tone level for the two fan configurations at the maximum (3.5 chord) rotor-stator spacing (fig. 12(a)). As fan speed is increased the pressure drop across the honeycomb-screen arrangement also increases and it therefore seems to better reduce the inflow disturbances. This effect is seen up to a speed of about 85% design speed, where the inflow-controlled results begin to approach those for the open inlet. This behavior may be due to the generation of rotor-alone noise as the rotor tip relative Mach number exceeds unity (which occurs at about 85% design speed).

The blade passing tone level does not change appreciably when, for the 88-vane cut-on stage, the rotor-stator spacing is reduced from 3.5 to 1.5 mean rotor chord lengths (fig. 12(b)). Thus, rotor-stator interaction appears to be relatively unimportant in the generation of the inlet-radiated blade passing tone.

A somewhat different picture emerges from the results for the first overtone (2 x BPF). It can be seen (fig. 12(c)) that vane number produces little or no effect at the 3.5 chord rotor-stator spacing without the inlet flow control device. With inflow control, the 112-vane fan configuration produces about 2 dB less tone than does the 88-vane fan.

Figure 12(d) shows, however, that there is also a spacing effect on this overtone level. Here at the lower fan speeds the 1.5 chord spaced configuration is about 5 dB noisier than the 3.5 chord spaced configuration, with little effect observed with the flow control device. As the fan speed is increased the flow control device becomes increasingly effective. Additionally, the results for the two rotor-stator spacings begin to merge as the fan speed increases above 80% design, where the rotor tip relative Mach number reaches unity. It appears that the first overtone is controlled by rotor-stator interaction at fan speeds less than 80% design for the close-spaced configuration, with the forward propagation of this tone being restricted by the sonic flow through the rotor at higher fan speeds. Thus, at higher fan speeds the overtone contribution due to rotor-inlet disturbance interaction dominates, and is seen to be somewhat reduced by the inlet flow device.

Inlet Turbulence

A radial hot film cross probe was traversed in the inlet duct at the location shown in figure 3. Axial and circumferential turbulence measurements were made for probe immersion from 0.66 cm (0.26 in.) to 12.95 cm (5.10 in.) from the inlet duct outer wall. To avoid acoustic effects due to the probe wake, these probe measurements were made separately from the acoustic measurements.

Similar turbulence measurements were made in the inlet duct of the research fan in reference 6. In these tests the circumferential turbulence intensities were reduced by a factor of 5 with tunnel flow (compared to no tunnel flow) with less significant changes in the other turbulence properties. It was concluded that the circumferential turbulence intensity plays a major role in rotor-inlet disturbance fundamental tone generation. The inlet flow control device described in the study was also tested in reference 6 (with no tunnel flow). The circumferential turbulence intensities were reduced to slightly below flight-simulation levels by the flow control device, however, axial turbulence length scales doubled relati to static, pen inlet conditions. The inlet flow control device partially reduced the fan fundamental tone level compared to that observed for flight simulation with tunnel velocity, suggesting that the tone level is somehow controlled by a combination of turbulence intensity and length scale. The anechoic chamber turbulence test results of the present study generally follow those reported in reference 6 with the exception of the axial turbulence length scale.

The axial turbulence intensity (fig. 13(a)) was not affected by the presence of the inlet flow control device in the free stream. A small reduction in axial turbulence intensity was observed at the measurement point nearest the wall, but no detailed boundary layer survey was made.

The circumferential turbulence intensity was considerably reduced at all probe immersions by the presence of the inlet device (fig. 13(b)). This turbulence component likewise increased in the boundary layer region, but not as much as did the axial component.

Figure 14 presents the axial turbulence length scale as a function of the probe immersion distance. The presence of the inlet device considerably reduced the axial length scale. This result is consistent with the reduction in blade passing tone level with the device installed, and follows Hanson's explanation (see refs. 2 and 3) of blade passing tone noise being generated by ingestion of turbulence structures sufficiently elongated to be intersected by several rotor blades.

The difference in the effect of the inlet flow control device on the axial turbulence length scale in the wind tunnel (ref. 6) compared to the anechoic chamber may be related to differences between the two installations. In the anechoic wind tunnel of reference 6 the inlet flow control device, through necessity, was close to the tunnel walls. It is possible that this proximity to the tunnel walls generated adverse inflow disturbances which could not be adequately removed by the inlet device.

Low frequency, constant bandwidth spectra for the axial and circumferential turbulence velocity at a location in the duct wall boundary layer are presented in figure 15. For each component there is more low frequency energy associated with the uncontrolled inlet flow. This result is consistent with the turbulence intensity results in the boundary layer of figure 13.

SUMMARY OF RESULTS

A research fan was run in an anechoic chamber with a honeycomb-screen inlet flow control device. The design configuration of the fan incorporated a blade-vane ratio for fundamental tone cut-off, and a rotor-stator spacing of 3.5 mean rotor chord lengths. Two additional configurations of the research fan with a reduced number of stator vanes (fundamental tone cut-on) were tested at rotor-stator spacings of 3.5 and 1.5 rotor chord lengths. A cross hot film anemometer was used in the fan inlet to measure the inflow turbulence structure. Significant results of these tests are as follows:

1. The presence of the inlet flow control device reduced the level of the blade passing tone by about 10 dB at some angular locations, giving about a 5 dB reduction in the sound power level at the fundamental tone frequency. However, the tone was not reduced to near broadband levels as had been observed in some flight measurements.

2. Considerable reduction in the turbulence circumferential intensity and axial length scale were observed with the inlet flow control device.

3. Rotor-inflow disturbance interaction was more important than rotor-stator interaction in the generation of inlet fundamental blade passing tone noise. However, the inlet first overtone (2 x BPF) levels are controlled by rotor-stator interaction at close spacing. At higher rotor tip speeds this source may be attenuated in the forward arc by propagation through the rotor when the tip relative Mach numbers are greater than one.

4. The inlet flow control device was especially effective in reducing the generation of shaft order tones to near broadband levels for near sonic rotor relative velocities. The shaft order tone generation was less affected by the device at higher fan speeds.

REFERENCES

1. Charles E. Feiler, and John F. Groeneweg, "Summary of Forward Velocity Effects on Fan Noise," NASA TM-73722 (1977); AIAA Paper 77-1319 (Oct. 1977).

2. Donald B. Hanson, "Measurements of Static Inlet Turbulence," AIAA Paper 75-467 (Mar. 1975).

3. Donald B. Hanson, "A Study of Subsonic Fan Noise Sources," AIAA Paper 75-468 (Mar. 1975).

4. B. K. Hoder, "The Effects of Forward Speed on Fan Inlet Turbulence and Its Relation to Tone Noise Generation," NASA TM X-62381 (1974).

5. H. F. Heidmann, and D. A. Dietrich, "Simulation of Flight-Type Engine Fan Noise in the NASA-Lewis 9x15 Anechoic Wind Tunnel," NASA TM X-73540 (1976).

6. L. M. Shaw, R. P. Woodward, F. W. Glaser, and B. J. Dastoli, "Inlet Turbulence and Fan Noise Measured in an Anechoic Wind Tunnel and Statically with an Inlet Flow Control Device," NASA TM X-73723 (1977), AIAA Paper 77-1345 (Oct. 1977).

7. B. W. Lowrie, "Simulation of Flight Effects on Aero Engine Fan Noise," AIAA Paper 75-463 (Mar. 1975).

8. J. P. Roundhill, and L. A. Schaut, "Model and Full-Scale Test Results Relating to Fan Noise In-Flight Effects," AIAA Paper 75-465 (Mar. 1975).

9. J. A. Wazyniak, L. M. Shaw, and J. D. Essary, "Characteristics of an Anechoic Chamber for Fan Noise Testing," NASA TM X-73555 (1977).

10. B. W. Lowrie, and D. R. Newby, "The Design and Calibration of a Distortion-Reducing Screen for Fan Noise Testing," AIAA Paper 77-1323 (Oct. 1977).

11. B. J. Cocking, and R. B. Ginder, "The Effect of an Inlet Flow Conditioner on Fan Distortion Tones," AIAA Paper 77-1324 (Oct. 1974).

12. J. M. Tyler, and T. G. Sofrin, "Axial Flow Compressor Noise Studies," SAE Trans. 70, 309-332 (1962).

13. T. F. Gelder, and G. W. Lewis, Jr., "Aerodynamic Performance of 0.5-Meter-Diameter, 337-Meter-per-Second Tip Speed, 1.5-Pressure-Ratio, Single-Stage Fan Designed for Low Noise Aircraft Engines," NASA TM D-7836 (1974).

E-?444

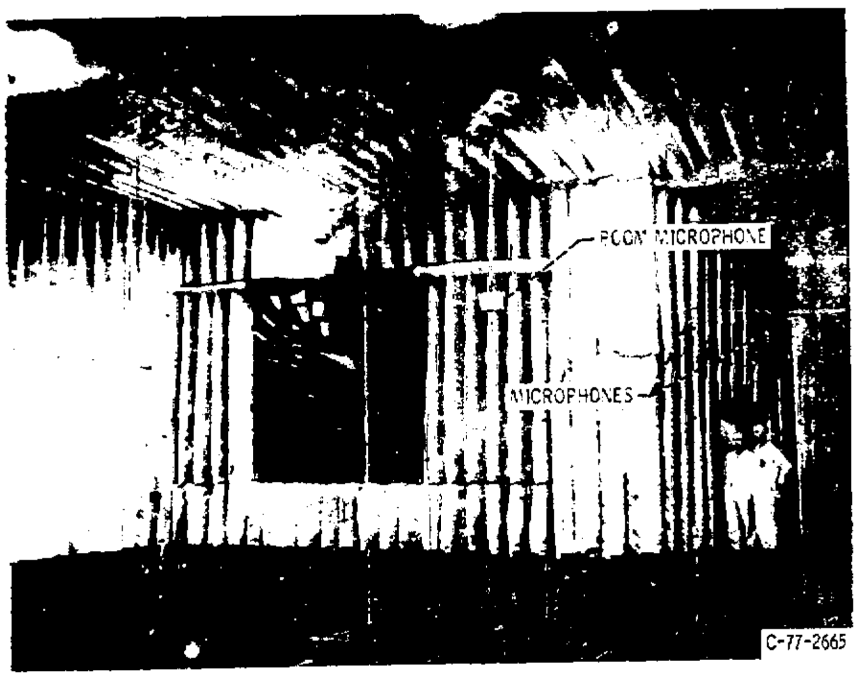
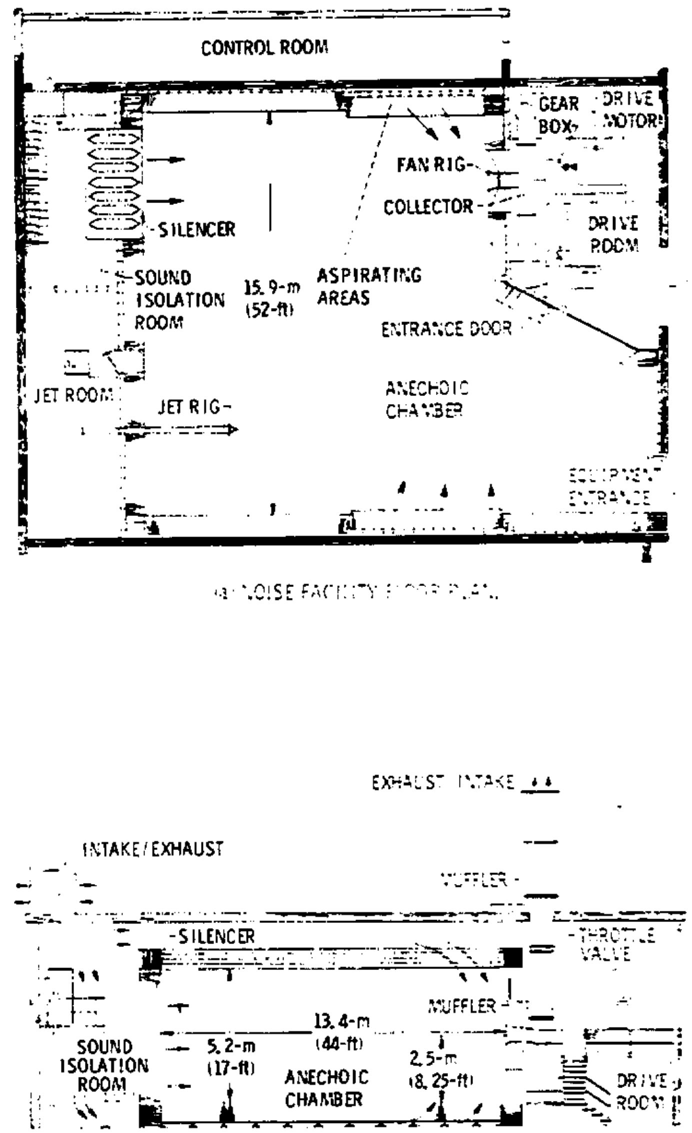


Figure 1. - Research fan installed in anechoic chamber.



(a) NOISE FACILITY FLOOR PLAN.

(b) NOISE FACILITY ELEVATION VIEW.

Figure 2. - Anechoic chamber.

ORIGINAL PAGE IS
OF POOR QUALITY

DESIGN PARAMETERS

ROTATIVE SPEED	13020 rpm
TIP SPEED	337.5 m/sec (1107 ft/sec)
STAGE TOTAL PRESSURE RATIO	1.499
MASS FLOW	29.2 kg/sec (64.4 lbm/sec)

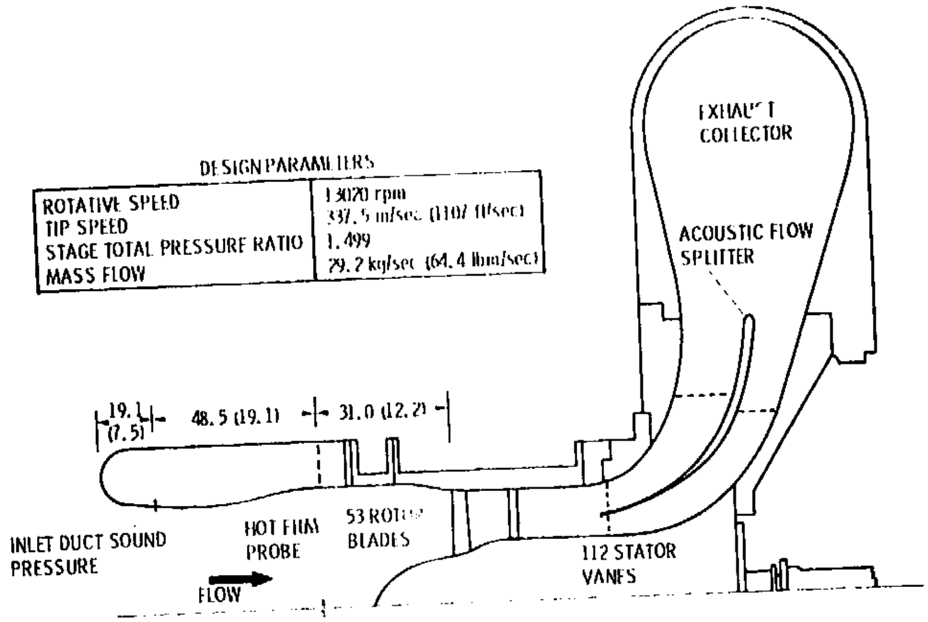


Figure 3. - Cross-sectional view of the research fan in the anechoic chamber and table of design parameters (dimensions are in cm (in.)).

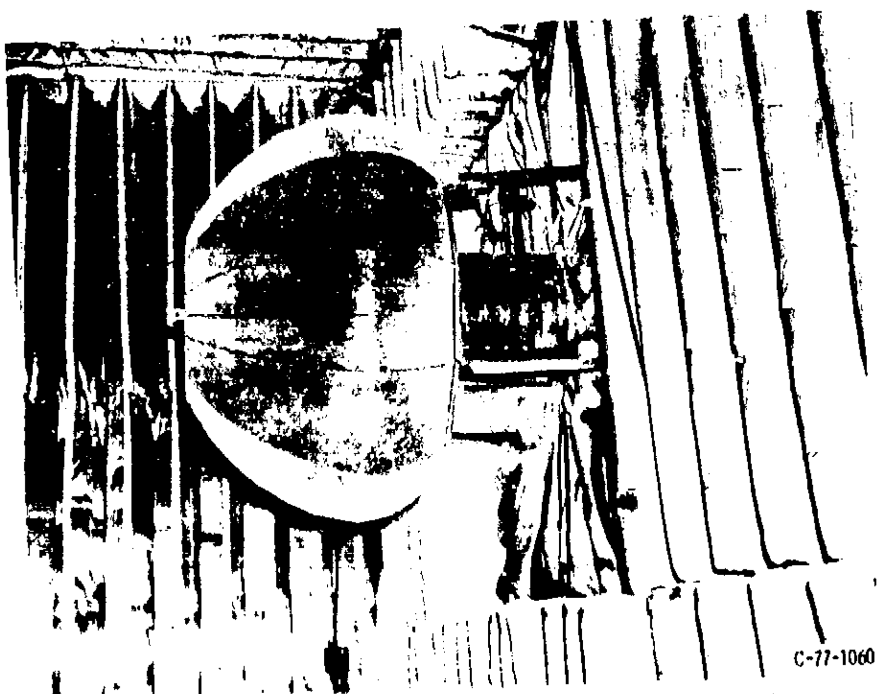


Figure 4. - Inlet flow control device installed on research fan in anechoic chamber.

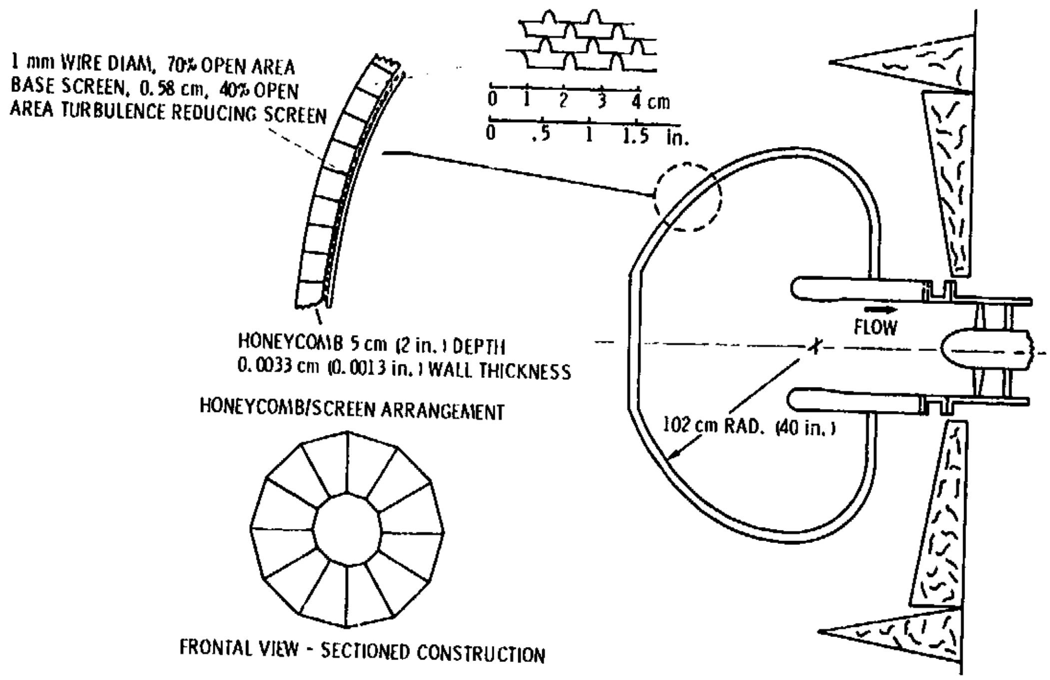


Figure 5. - Inlet flow control device.

ORIGINAL PAGE IS
OF POOR QUALITY

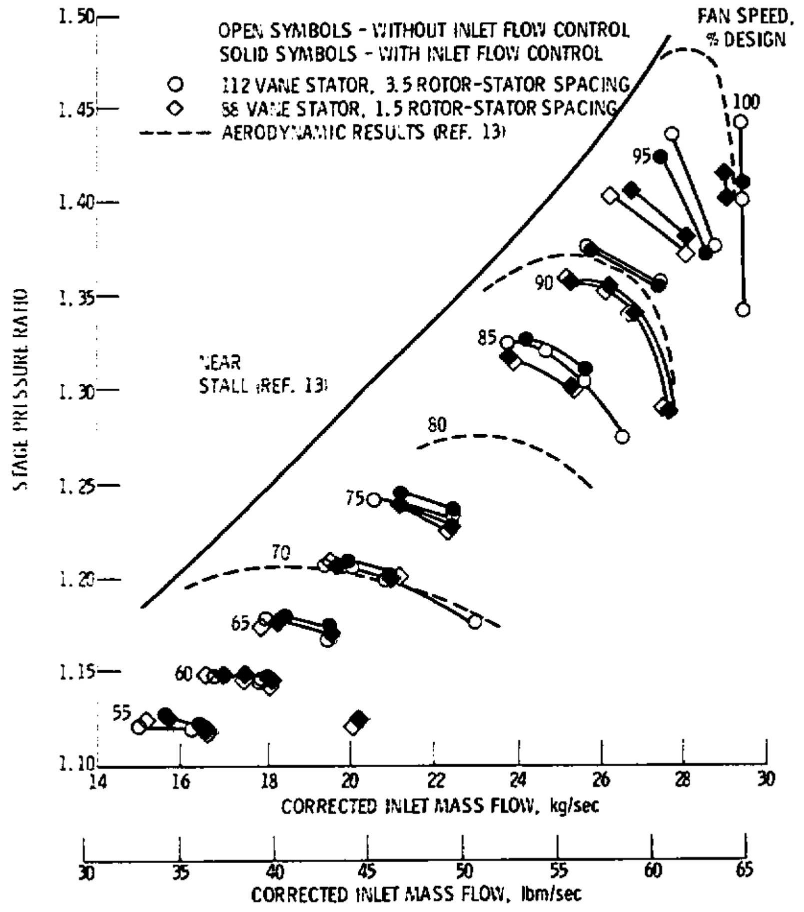
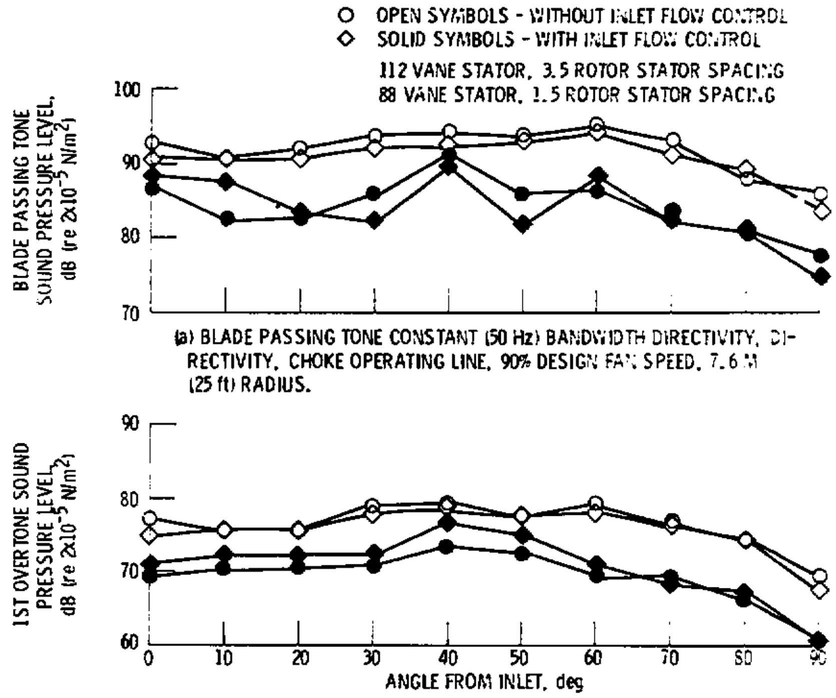


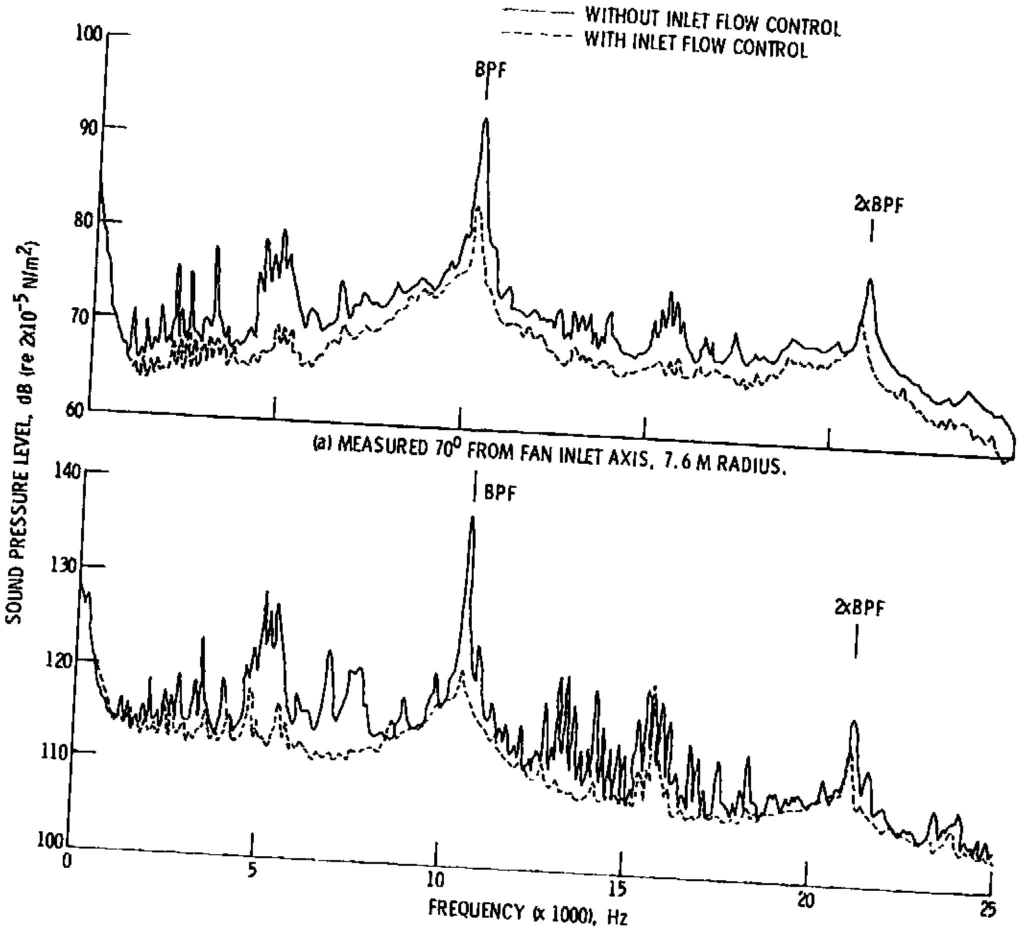
Figure 6. - Fan operating map.



(a) BLADE PASSING TONE CONSTANT (50 Hz) BANDWIDTH DIRECTIVITY, DI- RECTIVITY, CHOKE OPERATING LINE, 90% DESIGN FAN SPEED, 7.6 M (25 ft) RADIUS.

(b) 1ST OVERTONE (TWICE BLADE PASSING FREQUENCY).

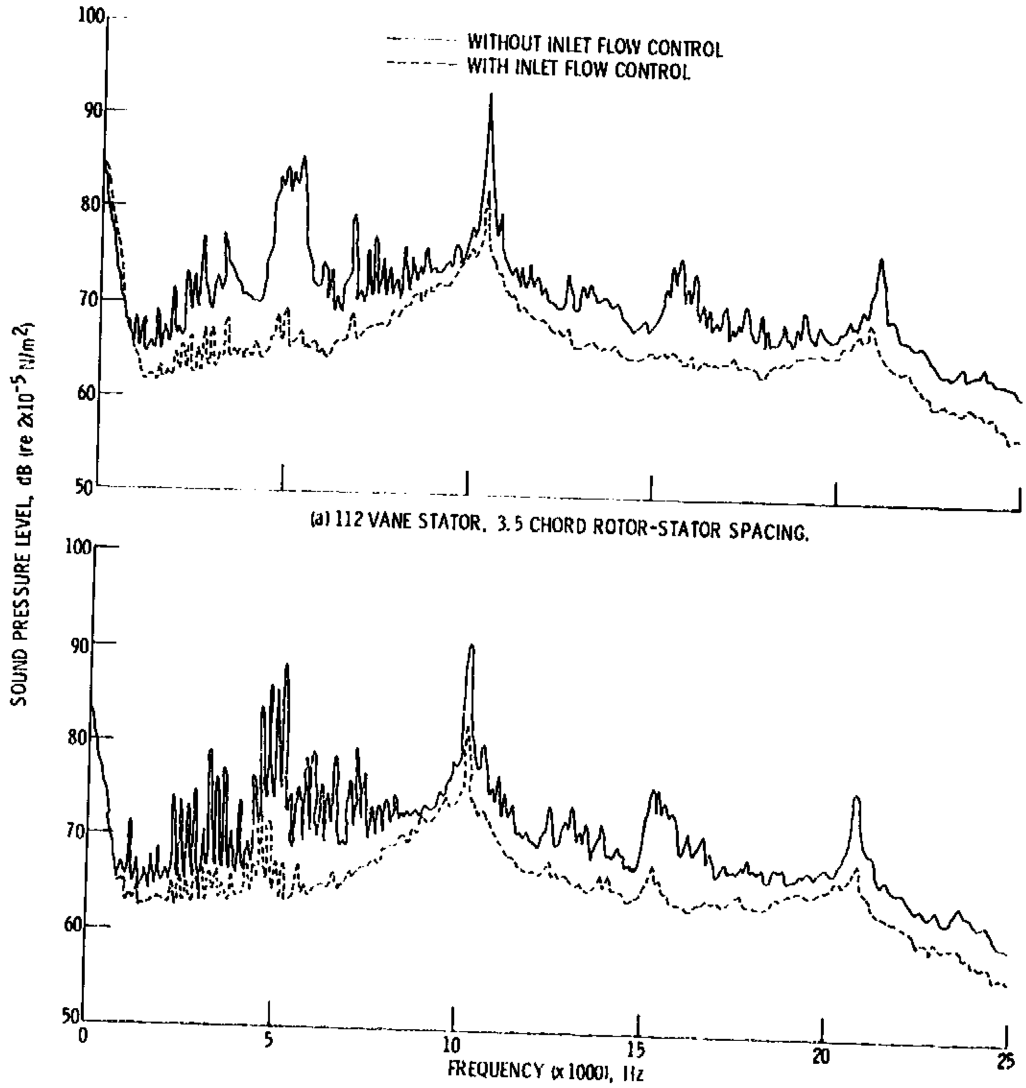
Figure 7.



(b) SPECTRA MEASURED IN INLET DUCT.

Figure 8. - Sound pressure level spectra, 90% design fan speed 112 vane stator, 3.5 rotor-stator spacing, standard operating line.

ORIGINAL PAGE IS
OF POOR QUALITY



(b) 88 VANE STATOR, 1.5 CHORD ROTOR-STATOR SPACING.

Figure 9. - Sound pressure level spectra, 70° from inlet, 90% design fan speed, choke operating line (bandwidth is 50 Hz).

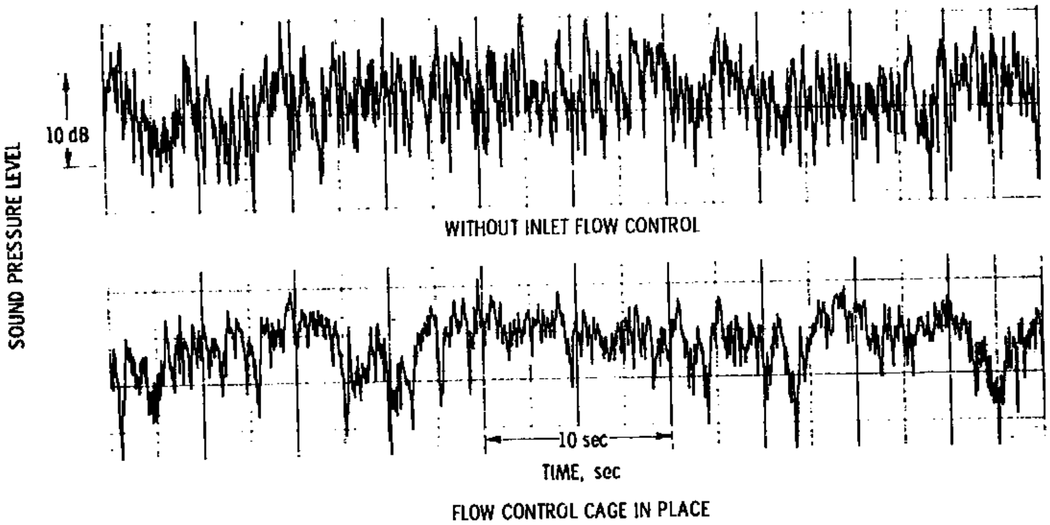


Figure 10. - Blade passing tone time history, 50 Hz bandwidth, 70° from inlet axis (design fan stage, standard operating line, 90% design fan speed).

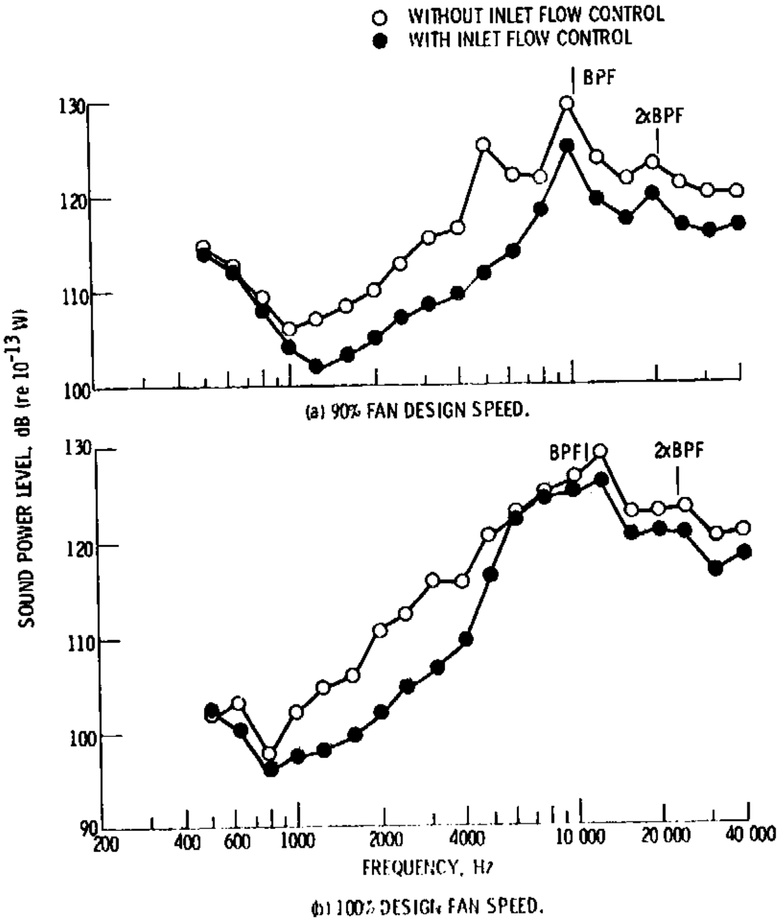


Figure 11. - One-third octave sound power level spectra, design (112 vane) fan, choke operating line.

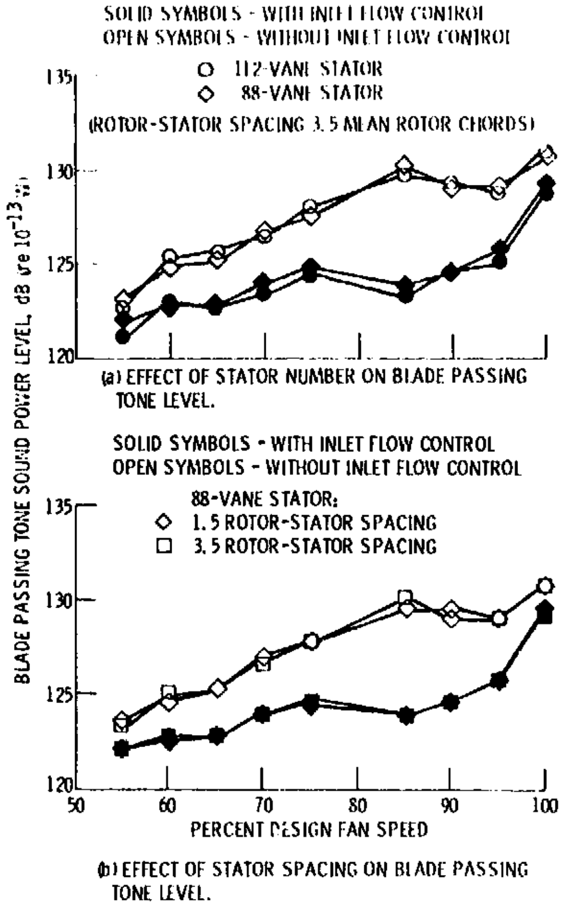


Figure 12. - Effect of inlet flow control device and fan speed on inlet sound power level (1/3 octave results) choke operating line.

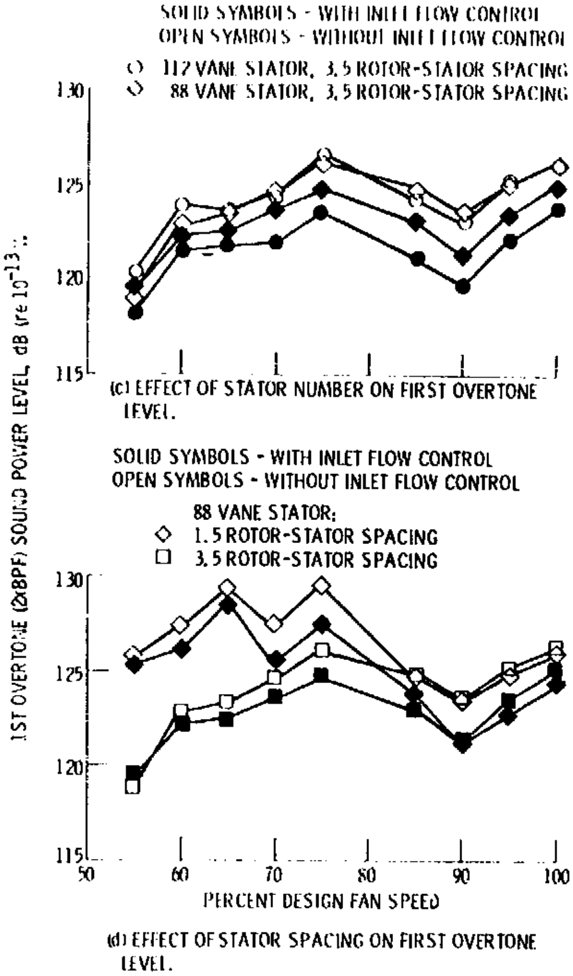


Figure 12. - Concluded.

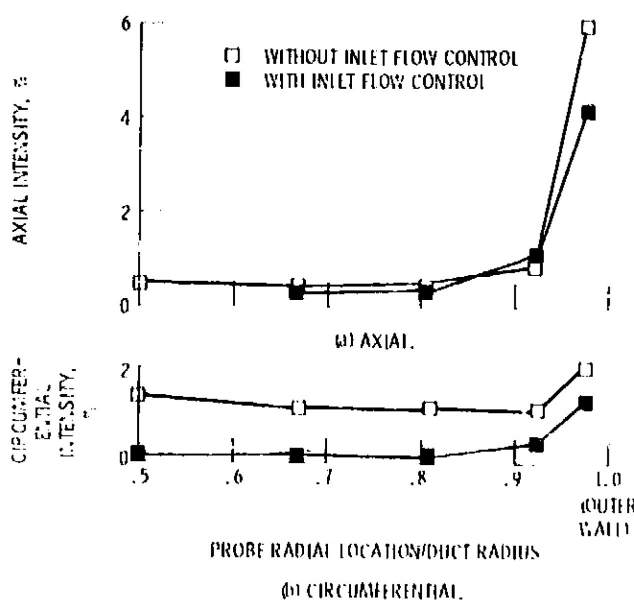


Figure 13. - Turbulence intensities, 90% fan design speed.

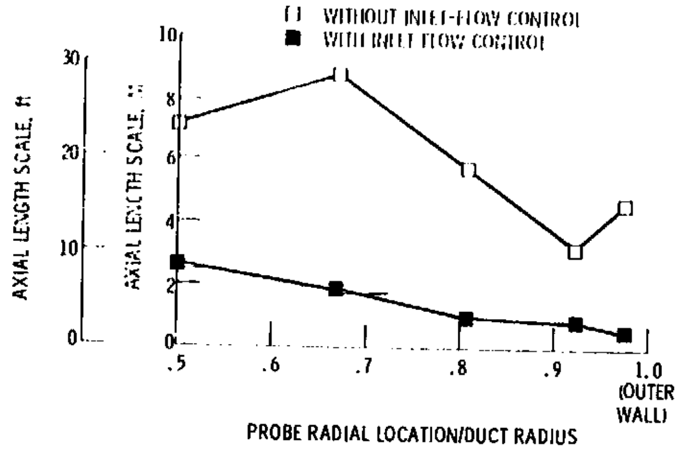
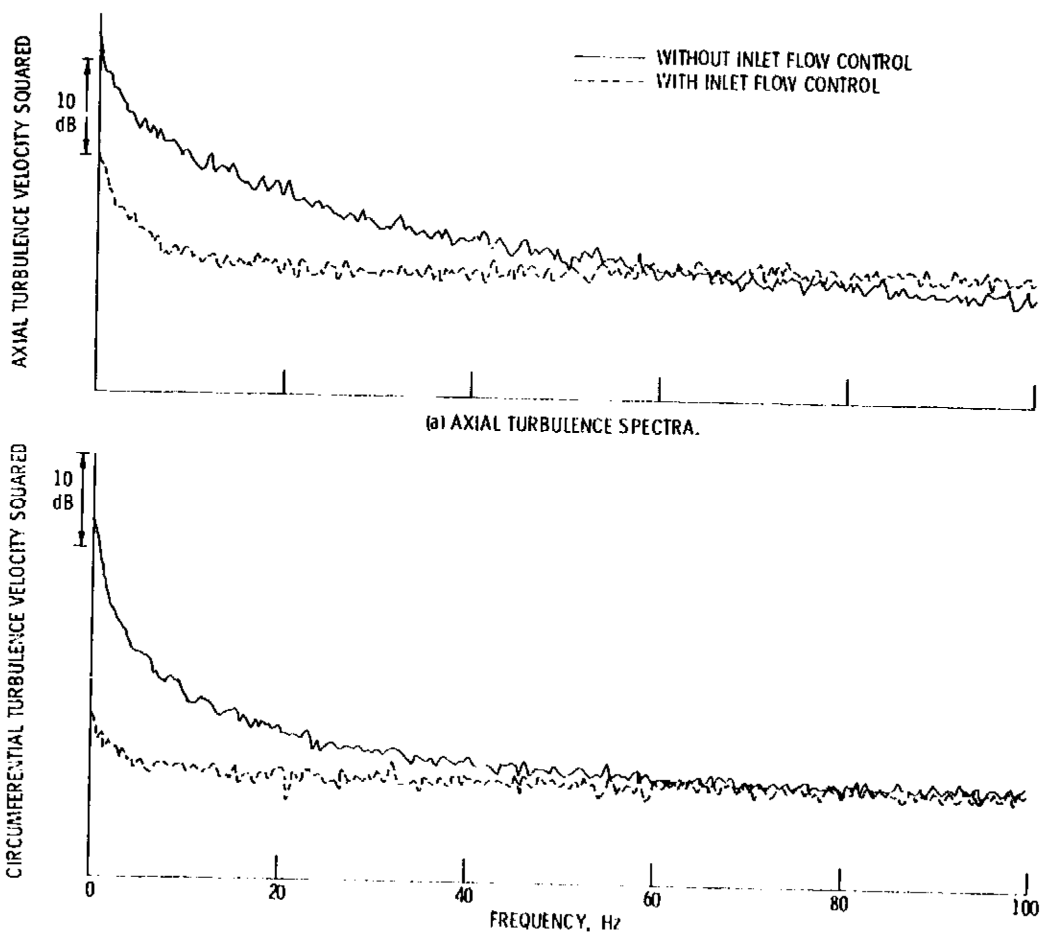


Figure 14. - Axial length scale, 90% fan design speed.

ORIGINAL PAGE IS
OF POOR QUALITY



(b) CIRCUMFERENTIAL TURBULENCE SPECTRA.

Figure 15. - Low frequency turbulence spectra, 90% design fan speed, measured 0.65 cm (0.26 in.) from outer wall of inlet.